CENTER FOR BEAM PHYSICS

PROGRAM OVERVIEW

Swapan Chattopadhyay

AFRD Review

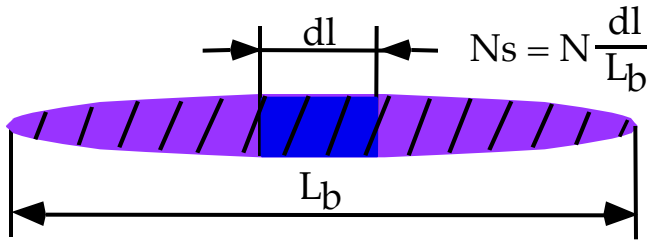
May 8-9, 1996

Academic & Visiting Scientists

- Faculty Associates
  - R. Falcone (lasers)
  - J. Wurtele (beam physics)
  - M. Shapiro (experimental laser-plasma detection)
  - J. Siegriest (experimental laser-plasma detection)
- Visiting Scientists
  - Y. Kishimoto, JAERI, Japan
  - J. Koga, JAERI, Japan
  - Y. Orlov, Cornell
  - R. Ryne, LANL
  - T. Tajima, UT Austin
  - V. Telnov, BINP
  - K. Yokoya, KEK
- Center Affiliates
  - W. Barletta
  - R. Gough
  - A. Jackson
  - R. Keller
  - C. Kim
  - D. Robin
  - R. Schoenlein
  - C. Shank
  - H. Nishimura
- Participating Guests
  - Five Emeriti scientists (A. Garren, G. Lambertson, J.Peterson, F. Selph, F. Voelker)
  - L. Schachinger

Advantages

1. Strength of incoherent signal on other beam particles (noise) depends on the number of particles in a sample, N_S



which is defined by the bandwidth of the overall system. (Compare 4×10^{13} Hz optical frequency bandwidth with 4×10^{9} Hz microwave frequency bandwidth). Correspondingly, OSC has a potential to 10^4 faster damping than microwave stochastic cooling.

2. Alternatively, for the same damping time as in microwave stochastic cooling (very slow of OSC) we find a difference in the required amplifier power:

0.1 W	for OSC
10^3 W	for microwave cooling

Advisory Committee for Experimental Program

Advisory committee is formed to look into a prioritized list of initial set of experiments at the BTF and L'OASIS laboratory by researchers & students nationwide.

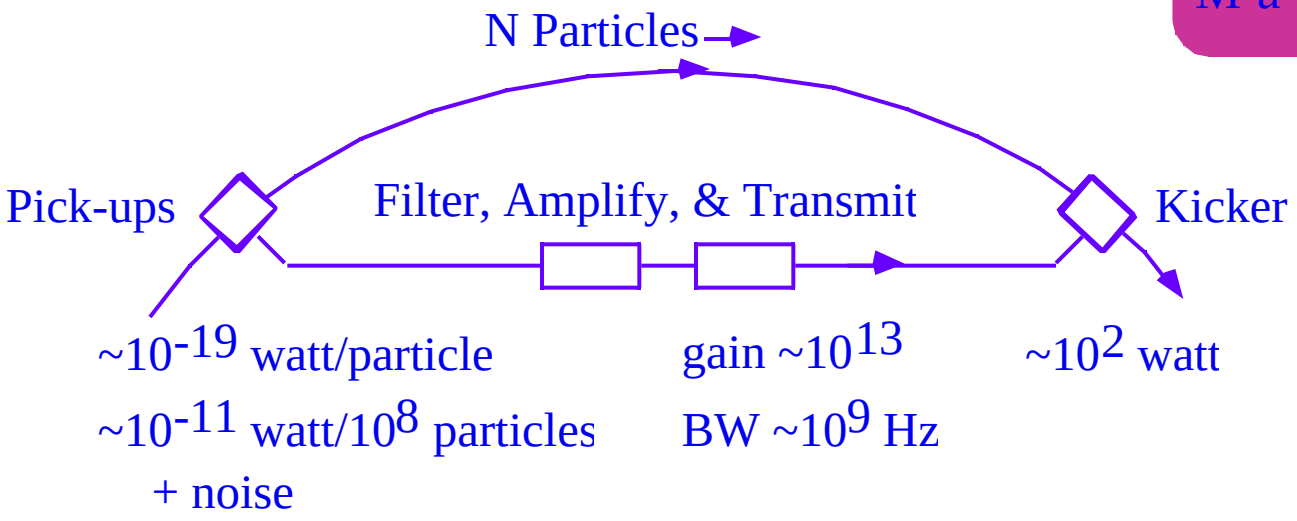
D. Burke, SLAC
E. Esarey, NRL
R. Falcone, UCB
C. Joshi, UCLA
N. Kroll, UCSD
G. Mourou, Univ. Michigan, Ann Arbor
R. Palmer, BNL
C. Pellegrini, UCLA
D. Rice, Cornell
D. Whittum, SLAC

Awards & Honors

- Faraday Cup for Beam Instrumentation : W. Barry
- D. R. Nicholson Humanitarian Award (APS) : A. Sessler
- APS VP-Elect : A. Sessler
- APS Fellowships : W. Barletta, S.Chattopadhyay, K.-J. Kim

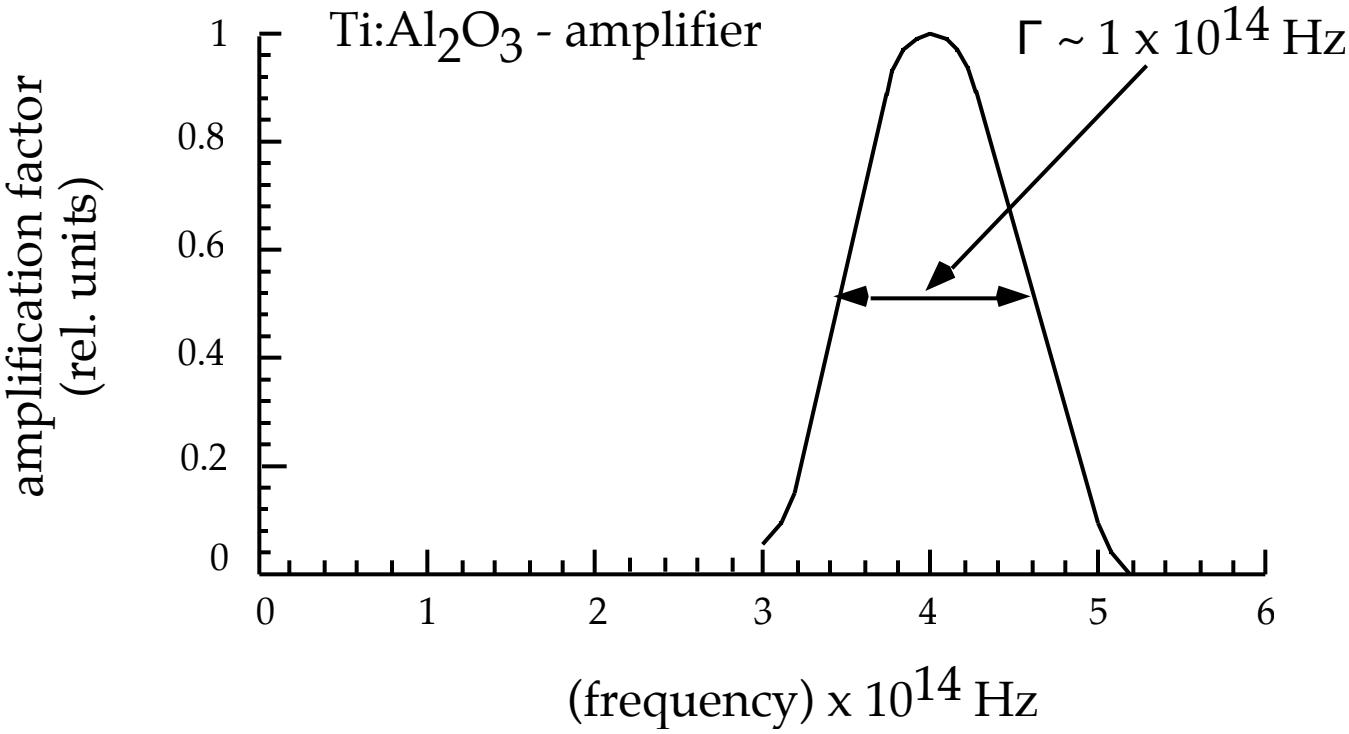
The Beam Cooling Scheme

Example #3
Phase-space
Manipulation

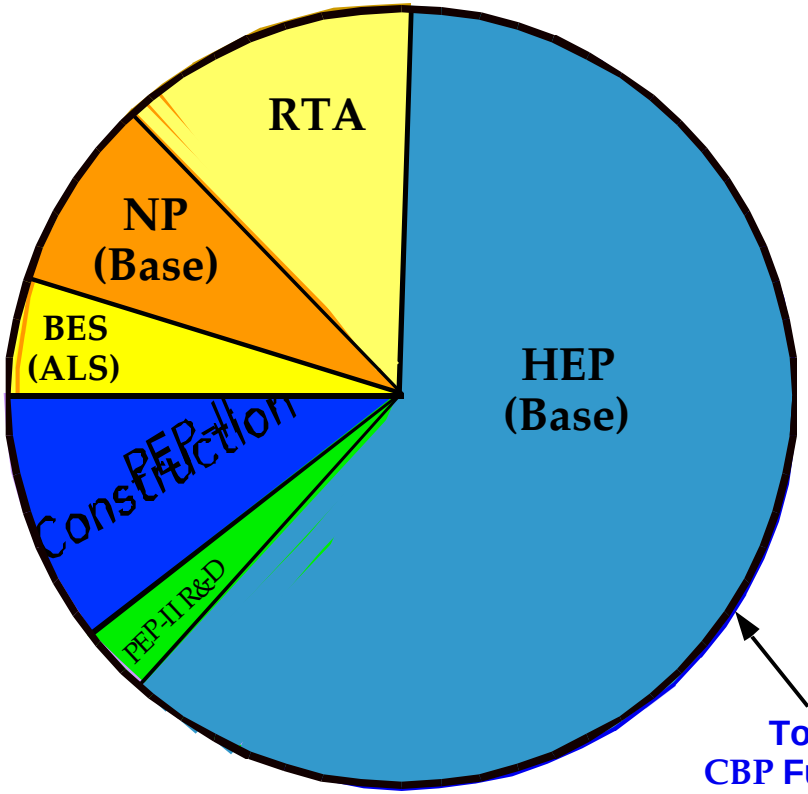


Signal/Noise ~ nV/μV

Broadband Optical Amplifiers ($Ti:Al_2O_3$, DYE)



CBP Budget : FY 1996



Operating:

HEP Base:	2,525 k$
PEP-II R&D:	110 k$
PEP-II Constr.:	4 FTEs
RTA :	570 k$

Equipment:

HEP Base:	223 k$

(100k$ held back due to PEP-II R&D funding shortfall)

PEP-II R&D:	40 k$

BES (ALS): RF and Beam Control in the Advanced Light Source
NP(Base): Phase Space Cooling of Heavy Ion Beams in RHIC (BNL)
PEP-II: Asymmetric B-Factory at SLAC (SLAC-LBNL-LLNL)
RTA : Relativistic Two-beam Accelerator

Consolidation of Experimental Infrastructure & Opportunities

- The Beam Test Facility provides access to the 50 MeV electron beam from the ALS injector linac transferred via a magnetic transport line into a specially shielded experimental vault, for experimental R&D in beam physics.
- Table-Top Terawatt laser already built via Laboratory Directed Research & Development funds. Another one already exists at the L'OASIS Laboratory.
- Components & plasma tests at the CBP L'OASIS Laboratory & the Lambertson Beam Electrodynamics Laboratory.
- Experimental plan fully developed.
- Local expertise in beam physics, plasma physics, high power & short pulse lasers, laser guiding, rf control & quantum optics is complete.

Consolidation of Experimental . . . con't

Consolidation of Experimental Infrastructure & Opportunities

con't

The CBP facilities provide a highly cost-effective program in frontier accelerator R&D, competitive & complementary to other international and national efforts. We expect definitive results in the next years on the following :

- Focussing of relativistic beams by plasmas.
- Demonstration of guiding & confining high field gradients over long distances (1 GeV/ m over a macroscopic length of a few cm to a meter).
- Detailed field & phase space dynamics mapping over the "confined channel".
- Feasibility & utility of Femtosecond Thomson x-ray source.
- Feasibility & utility of Storage Ring Femtosecond x-ray source.
- Optical Stochastic Cooling.

Educational Activities

- US Accelerator Schools :
  - UC San Diego, Winter '95-'96 (Beam Electrodynamics Group)
  - University of Maryland, Fall '96 (J. Byrd)
  - US-Japan Accelerator School, '96 (J. Byrd)
  - UC Berkeley, Winter '97 (planned)
- United Nations UNESCO School on Synchrotron Radiation, March '96 (K.-J. Kim)
- Regular graduate courses at UCB (Wurtele, Kim, Chattopadhyay)
- Graduate Seminar Class at UCLA (Barletta)
- CBP Seminars
- Editorship of Particle Accelerators & Nucl. Instr. Methods in Phys. Res. A
- Total number of students involved in program :
  - 11 graduate and undergraduate students altogether

Effort Breakdown

FTEs	
4	PEP-II Construction
3	PEP-II R&D (including 2.5 FTE from Base)
5	RF Power Source/RTA (including 2FTE from Base)
4	Accelerator Theory, Advanced Accelerator Methods, Lepton Colliders & Experimental Program
1	ALS RF, Feedback & Instabilities
1.5	Beam Cooling for RHIC
2.5	Technical Associates
3	Administration
2	Students

Total : 26 (15 from HEP Base)

Experimental Facilities

- Beam Test Facility (BTF) at the ALS : Scheduled experiments and committee
- Lambertson Beam Electrodynamics Laboratory
- L'OASIS (Laser, Optics & Accelerator Systems Integrated Studies) - - New facility under preparation
- Relativisitc Two-beam Accelerator (RTA) Facility, Building 58

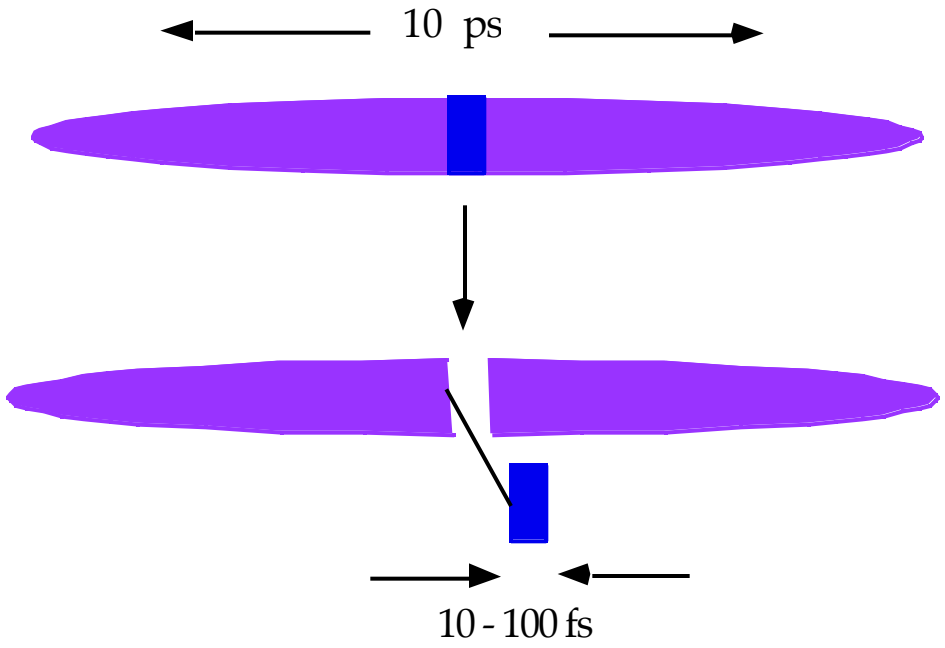
Experimental Program

- **Beam Focussing**
- **Laser-Electron Beam Interaction**
- **Novel RF Structures**
- **Novel Diagnostic Techniques**
- **Laser Acceleration :**
  - **Generation of high gradients over long distances by laser-plasma wakefields (with guiding).**
  - **Systematic mapping of field configuration & dynamic phase-space acceptance of acceleration channel by high quality, spectrally pure beam.**
- **Optical Cooling & THz Signal Processing**
- **THz power sources**

Femtosecond Laser - Electron Beam Interaction

Femtosecond 'Tickle' and Slicing of Picosecond Electron Beams

Example #2
Ultrafast
Processe

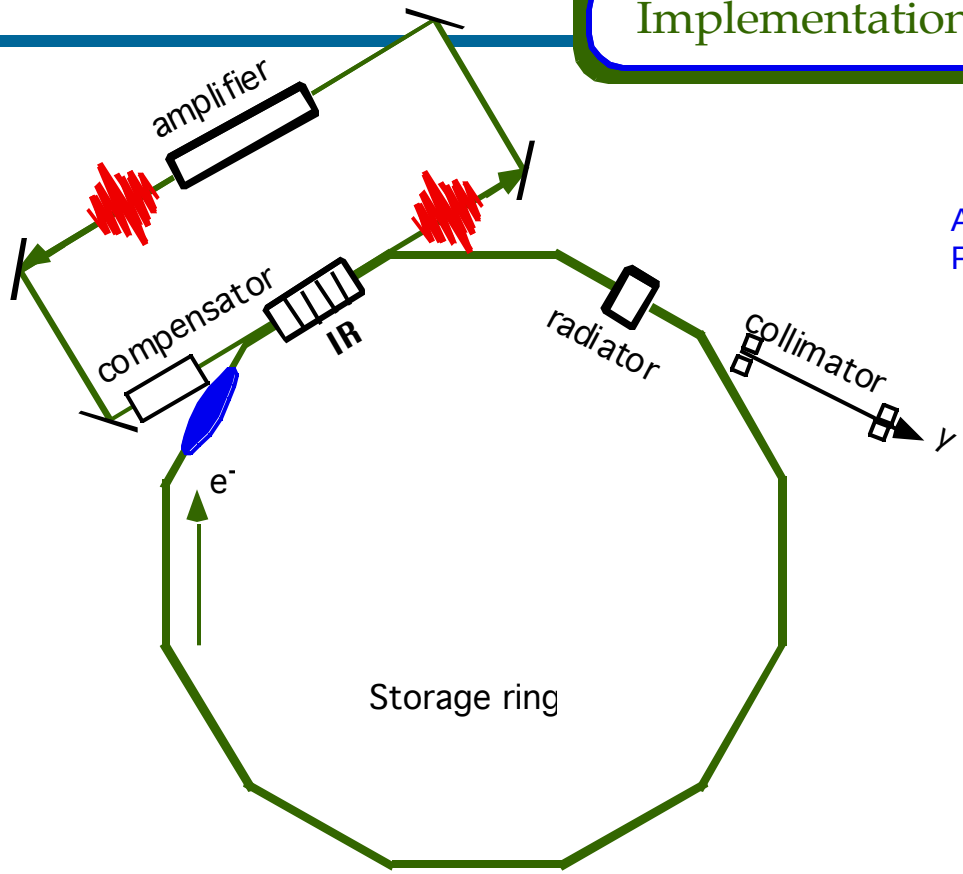


High Frequency Diagnostics, Optical Stochastic Cooling for Future Colliders, Femtosecond Sources, etc.

- Beam manipulation on a femtosecond time scale (i.e. THz frequency scale)
- Stochastic phase-space cooling at optical frequencies
- Applications and relevance to :
  - TeV 33 (to achieve the high luminosity)
  - Muon cooling
  - Laser acceleration, linear colliders, etc.
  - Femtosecond x-ray sources

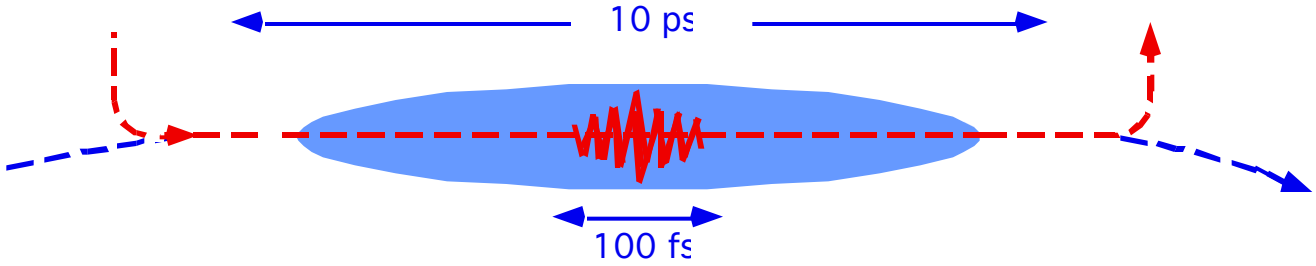
Femtosecond Slicing in a Storage Ring

Implementation in the ALS



A.A. Zholents & M. Zolotorev,
Phys. Rev. Lett. 76, 916-918 (1996)

Example #2
Continued



Laser Manipulation of Beams — A New Thrust

Prelude :

The microwave technology at frequencies between a few MHz and a few GHz has been the work horse for particle accelerators since World War I and II. Powerful radio frequency power sources — such as cw tetrodes and pulsed klystrons, with a great deal of flexibility in amplitude, phase and frequency control — have been the drivers of particle storage and acceleration in circular and linear accelerators. Along with such versatile power sources, came the necessity to control and manipulate particle beams via radio-frequency electromagnetic fields to a high degree of precision. The RF and beam feedback systems, bunch rotators and Landau cavities, etc. all have been employed successfully to benefit collider operation. As the science and technology of RF progressed, the demands on the spectral purity of RF components for accelerator applications rose precipitously.

Memoranda of Collaboration and MOUs

- PEP-II (SLAC/LBL/LLNL)
- SLAC/LBL/LLNL on Next Linear Colllider (NLC) ZDR
- CERN-CLIC/LBNL-CBP on Two -Beam Accelerator
- UC Davis/LBNL/SLAC - ATRI on Microwave Technology
- UC Davis-NEG/LBNL-CBP - AXF photocathode gun at 11.4 GHz

Informal collaboration with MIT on 17.4 GHz electron gun

POTENTIAL:

Memoranda of Collaboration and MOUs

- BINP-LBNL - Gamma-Gamma Collider
- LLNL-LBNL - High Average Power Lasers for HEP
- LBNL-BNL-FNAL - Muon Collider Studies
- LBNL-BNL-FNAL - LHC Studies
- CESTA-LBNL - Collaboration on TBA Studies

Mission

- Research and Development for the production, manipulation, storage, and control of particle and photon beams as applied to fundamental studies in natural sciences, energy sciences, industry and commerce.

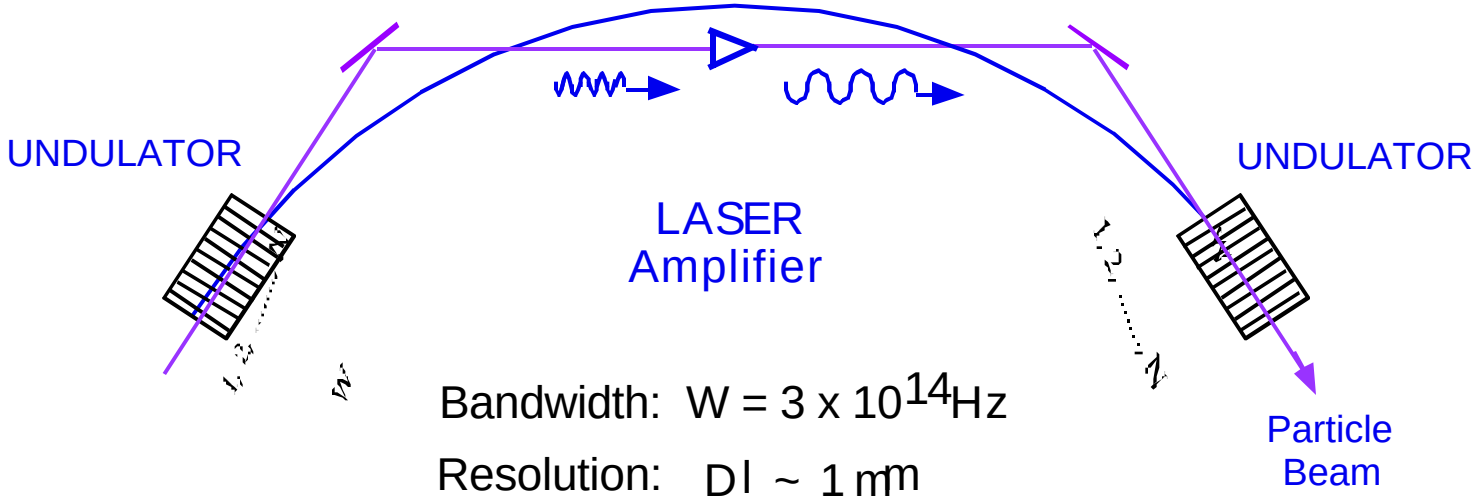
  High Energy Physics, Nuclear Physics, Material and Chemical Sciences, Life Sciences, ...

- Education of students, would-be practitioners and other segments of the community.

Optical Stochastic Cooling

The Idea

A. Mikhalichenko & M. Zolotorev,
Phys. Rev. Lett. 71, (25), 4146 (1993).



Bandwidth: $W = 3 \times 10^{14}$ Hz

Resolution: $\Delta l \sim 1\ \mu m$

Gain: $g \sim 10^7$

$$\#\text{Photons/ charged particle} \sim a\ N_W\ K^2$$

Weak undulator : $K \sim 0.1 \Rightarrow n_g / n_e \sim 1/137$

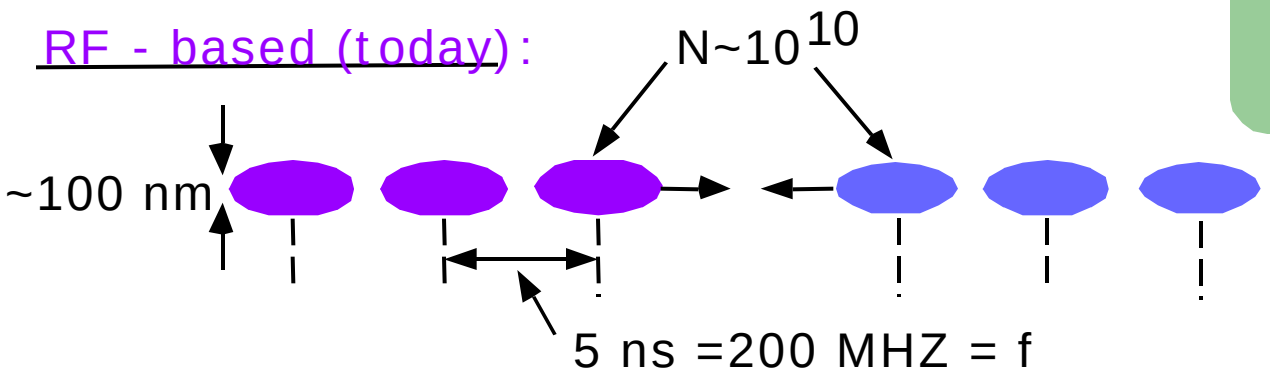
Strong undulator : $K \sim 1 \Rightarrow n_g / n_e \sim 1$

- Quantum Noise
- Signal/ Noise
- Coherent Radiation

Operations of Increasing Order in Smaller Dimensions and Higher Frequencies

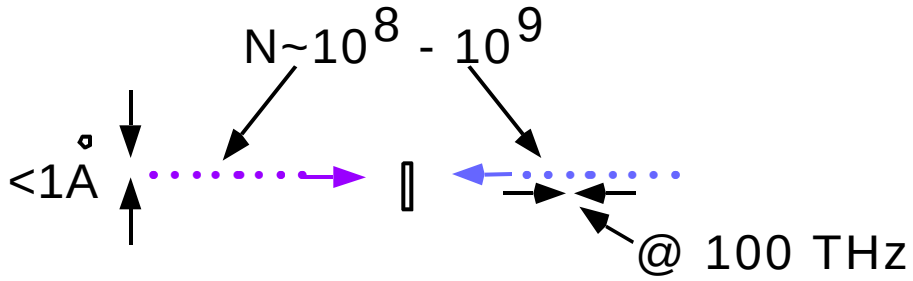
Example #1
Colliders

RF - based (today):

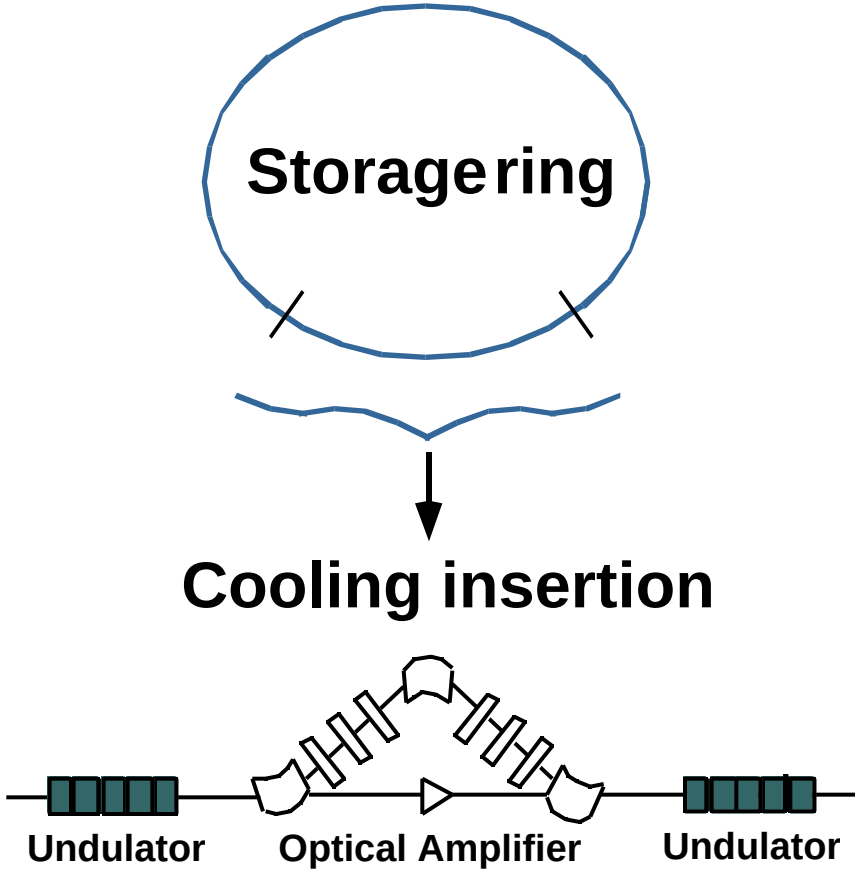


Drivers	Structures
RF ~ Ghz	cm.s
Super RF ~ 100GHz	mm
THz	100μm
Lasers	μms in plasmas

Laser-based:



Optical Stochastic Cooling

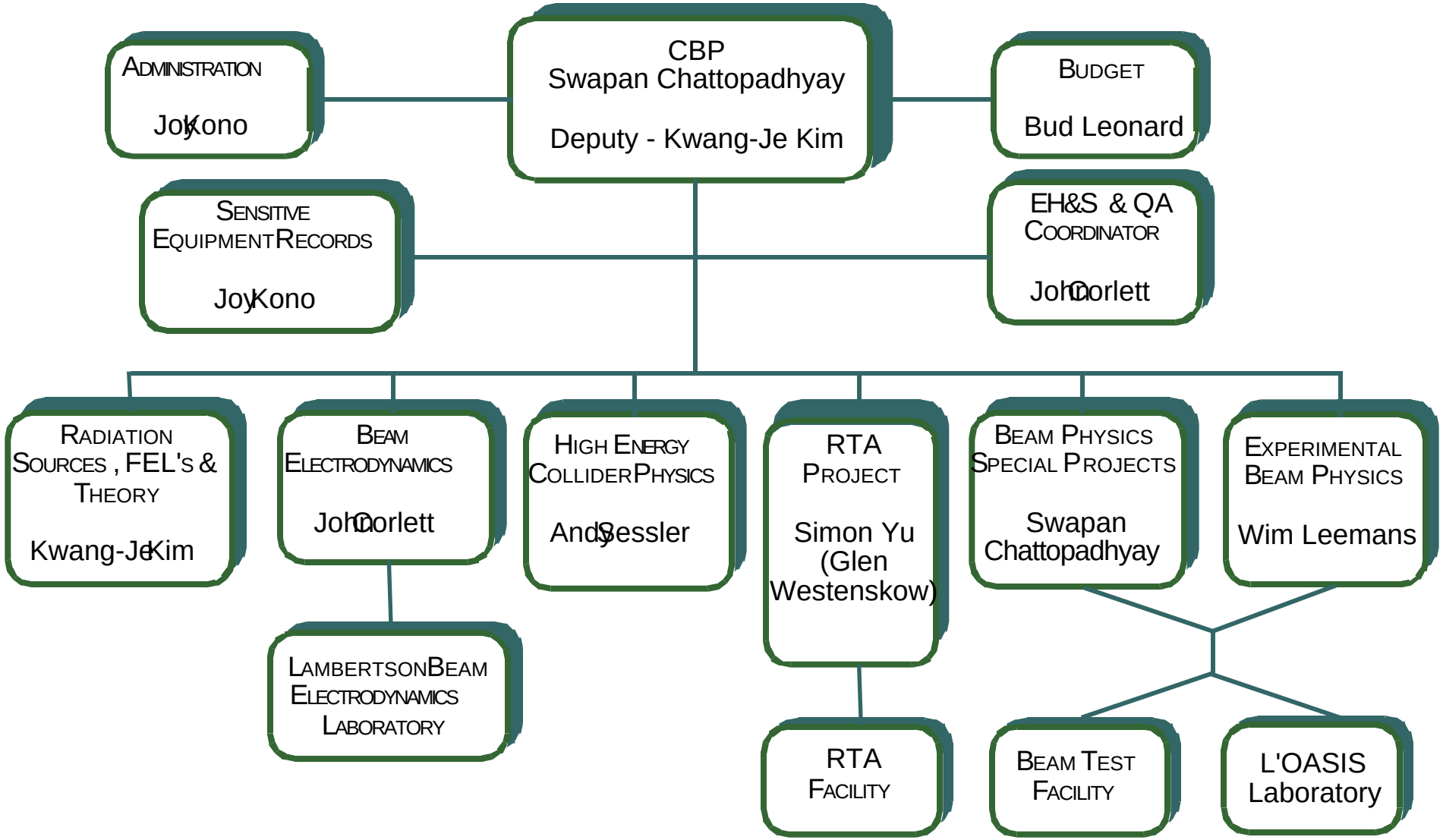


Bypass forces each particle to meet its own amplified radiation in the second undulator where it receives a "coherent" energy kick due to interaction with this radiation.

A. Zholents & M. Zolotorev,
Phys. Rev. E50 (4), 3087 91994)

CENTER FOR BEAM PHYSICS

Organization



- Mission
- Scope
- Research Program
- Research Output : Comments
- Consolidation of Experimental Infrastructure & Oppportunities
- Experimental Program
- Effort Breakdown
- Budget
- Staff
- Experimental Facilities
- Organization
- Memoranda of Collaboration & MOUs
- Educational Activities
- Sponsored Conferences & Workshops
- Awards & Honors
- Outstanding Budget Items
- Publications

- Laser Manipulation of Beams — A New Thrust

Outstanding Budget Items

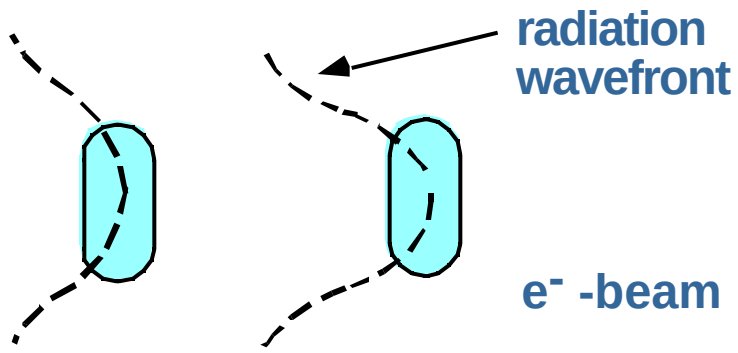
Year	Programs	Incremental Operating funds for the BTF	Incremental Equipment funds for the BTF	PEP-II R&D	Optical Cooling Beamline Equipment
FY '94	Requested	2 FTE	$230 k	$500 k	0
	Funded	0	0	$150 k	0
FY '95	Requested	2 FTE	$230 k	$500 k	$470k
	Funded	0	0	$444 k	0
FY '96	Requested	2 FTE	$230 k	$700 k	$470k
	Funded	0	0	$110 k	0
FY '97	Requested	2 FTE	$230 k	$700 k	$470k
	Funded	?	?	?	?

Primary Focus of the Experiment is to Understand :

- **Photon statistics and phase space d•o•f•**
- **Overlap —"transverse"—of the electron beam and undulator radiation wavefront**
- **Coherence volume in the transverse plane :**

$$s_x s_{x\perp} \sim D$$

- **Distortion of radiation wavefront due to amplification, propagation, etc.**



Research Output : Comments

- Large student participation & training
- Publications : many
- Leading contributions to initiatives in HEP :
  - PEP-II : new program launched in US-HEP
  - Gamma-Gamma IR in Linear Colliders
- General contributions to High Energy Physics :
  - FNAL ($\bar{p}$ source, cooling) ; permanent magnet storage ring for antiproton accumulation
  - SSC 1980-84 : Snowmass studies, etc.
    1984-88 : Central Design Group
    1988-93 : Consulting + magnets + detailee, etc.
  - PEP-II : initiated & now funded
  - LHC/NLC : continuing
  - Advanced accelerator concepts & beam physics experimental program : continuing

Research Output.....con't

Research Output : Comments con't#2

- Many advanced tools & state-of-the-art codes developed & shared with community towards collider & SR source conception & design e.g., codes & methodologies for nonlinear dynamics in storage rings based on modern analytical & numerical algorithms using Lie - and Differential-algebraic techniques, symplectic integration, etc. Complete set of codes already used by other labs (CERN, SSC/LHC, SLAC, BNL, KEK, FNAL, DESY, etc) : TRACY-II, THOR, DAPASCAL, Six Track, ZAP, ABCI, MOSES.

- Beam Test Facility (BTF) : Advanced Experimental Facility made available to the community for carrying out forefront R&D in advanced accelerator concepts in support of colliders & radiation sources of the future. (W. Leeman's talk)

- New facility under preparation : L'OASIS (Laser-Plasma, THz & Quantum Optics for high energy physics & radiation source studies).

- Industrial Collaboration : Haimson Research, Inc. on advanced accelerator rf development. Positive light on laser development.

- Integrated with National Effort on US-CERN collaboration on the LHC & member of the International Collaboration on Linear Colliders via Interlaboratory MOU. Integrated with National Effort on Muon Colliders.

Research Output.....con't

Research Output : Comments con't#3

- Significantly creative contribution :
  - PEP-II : new program launched in US-HEP based on asymmetric collider rings
  - Gamma-Gamma IR in Linear Colliders (Kwang-Je Kim's talk)
  - RTA Power Source beyond 1 TeV e^+e^- collisions (Simon Yu's talk)
  - Femtosecond x-ray sources (talks by Wim Leemans & Sasha Zholents)
- Consolidation of expertise & resources in high power (Terawatt), short pulse lasers, plasmas, electron beams & optical guiding towards experiments on ULTRA-HIGH GRADIENT ACCELERATION & other advanced methods.

Research Output : Comments con't #1

- Contribution specific to Radiation Sources :
  - Conception, design, construction & commissing of the Advanced Light Source (ALS).
  - Collaborative work at PLS (Korea), Sincrotron Trieste (Italy), SRRC (Taiwan), SLS (Switzerland), SPring-8, . . .
  - R & D on FELs & Novel Radiation Sources. (CDRL @ LBL, LCLS @ SLAC, CEBAF IR/UV FEL, DESY/TESLA FEL, National Collaboration on SASE/FEL Demonstration, Power Beaming, Femtosecond x-ray sources, etc.).

Research Output.....con't

ResearchProgram

Current Activities & Future Opportunities

- High Energy Collider Frontier:

  Hadrons & Heavy Ions :

  - TeV*, LHC
  - RHIC (talk by Rimmer)

  Leptons :

  - PEP-II B-Factory (talks by Zisman, Furman & Rimmer)
  - NLC: e^+e^-, Gamma-Gamma and Muons (talks by Kim, Rimmer, Yu)
  - Two Beam Accelerator (talk by Yu)

- Radiation Sources :

  - Fourth Generation Sources & FELs (talk by Kim, Leemans & Zholents)

- Advanced Concepts & Technologies:

  (Laser acceleration, Plasma Focussing, Femtosecond x-ray source, ... etc.)

  - New Thrust: Laser Manipulation of Beams

Scope

- The Center is involved in the conception, design, construction and commissioning of high energy colliders & synchrotron radiation sources (including FELs), in beam physics R & D for advanced acceleration & radiation methods & in detailed measurements & proof-of-principle experiments in its four major facilities — the Lambertson Beam Electrodynamics Laboratory, the CBP L'OASIS Laboratory, the Beam Test Facility at the ALS & the RTA facility.

- The Center continues to provide core accelerator physics support for the Advanced Light Source (ALS), the PEP-II, LHC/NLC studies and has major collaborations with SLAC, LLNL, BNL, FNAL, Stanford University, University of California at Davis and University of California at Berkeley.

- Significant benefit is derived from existing accelerator programs & infrastructure, supported by various divisions of DOE. (e.g. BES/ALS for BTF, Fusion for RK-TBA & NP for Beam Cooling.)

Sponsored Conferences and Workshops

- Mini Workshop on Laser Acceleration — 1995
- Ettore Majorana @ Erice on High Field Superconducting Magnets — 1995
- ICFA Nonlinear Dynamics Workshop — 1996
  @ Arcidosso, Italy together with SLAC and UCLA
- Advanced Accelerator Workshop — 1996 @ Lake Tahoe
  (sponsored by DOE/HEP)
- Superconducting Magnet — 1996
- RLHC — November 1996

Staff Roster

Scientists & Engineers :

BARRY, Walter
BYRD, John
CHATTOPADHYAY, Swapan
CORLETT, John
FAWLEY, William
FURMAN, Miguel
GOLDBERG, David
JOHNSON, Jimmie
KIM, Kwang-Je
LEEMANS, Wim
RIMMER, Robert
SESSLER, Andrew
TURNER, William
XIE, Ming
YU, Simon
ZHOLENTS, Alexander
ZISMAN, Michael
ZOLOTOREV, Max

Post-Docs :

CHENG, Wen-Hao
SHADWICK, Brad

Technical Support :

ARCHAMBAULT, Leon
LOZANO, David
DOUGHERTY, Jim

Administrative Support :

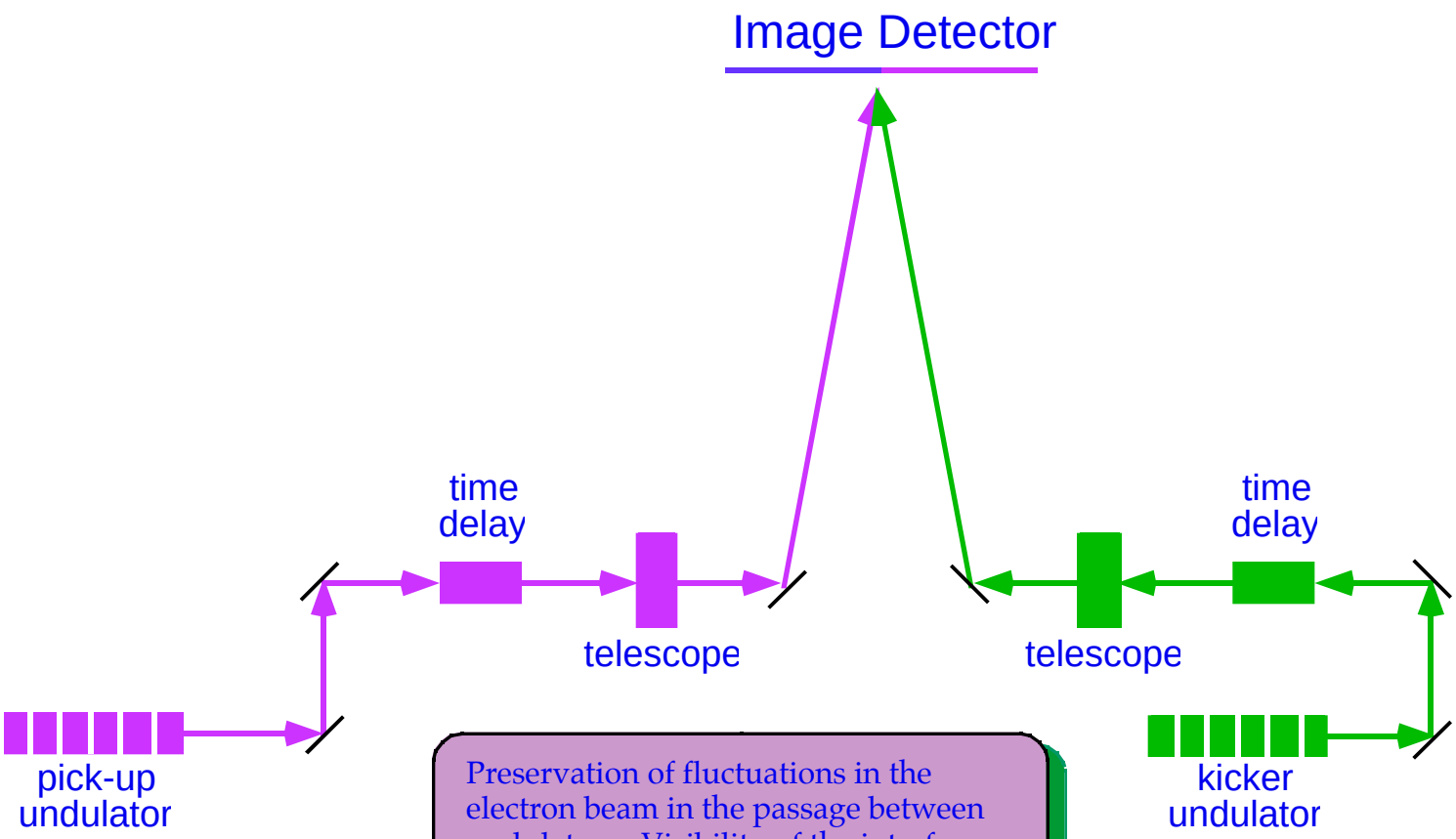
KONO, Joy
VANECEK, "Sam"
WONG, Olivia

Students :

BACCHUS, Ian
BRYANT, Tyler
DRAESEKE, Andrew
FAIGUENBLAT, Mikhail
GOVIL, Richa
IRWIN, Mike
LEE, Peter
LIE, James
PONCE-MARQUES, David
SCHROEDER, Carl
VOLFBEYN, Paul

(funded by UCB)

Test of "Non-Mixing" via Fringe Visibility



Preservation of fluctuations in the electron beam in the passage between undulators. Visibility of the interference pattern :

$$\text{Visibility} = \exp\left[-\frac{(k\Delta\ell)^2 + (\Delta k\ell)^2}{2}\right]$$

Today we are contemplating going beyond the GHz microwave rf technology to mm-wave and even THz radiation sources and eventually, maybe to state-of-the-art short -pulse high -power compact lasers as work horses for particle accelerators. There exist possibilities of generating ultrahigh electromagnetic fields by coupling these sources and today's lasers either to a channel in free space with suitable boundaries or to a suitable macroscopic medium like a plasma. However, just as in today's microwave technology involving beam manipulation over fractions of mms in time-scales of picoseconds at frequencies of GHz, one would have to learn to manipulate and control signals and particles at optical wavelengths of microns , in time-scales of femtoseconds, at frequencies of THz and higher in order to take advantage of today's lasers. For example, the development of femtosecond kickers, choppers, bunch rotators etc., and THz manipulation of beams will be one of the most challenging jobs for beam scientists, but needs to be accomplished for further progress.

- Demonstration experiment planned using the LBNL Advanced Light Source Booster Synchrotron. Preliminary beam measurements indicate that AN EXPERIMENT TO DEMONSTRATE THE FEASIBILITY OF THE THz SIGNAL EXTRACTION FROM AN ELECTRON BEAM IS ENTIRELY POSSIBLE WITH THE ALS BOOSTER BEAM.

- A magnetic lattice with suitable properties have been designed.

- A considerable amount of leverage is provided by the interest of the ALS accelerator staff in demonstrating the experiment. (See the design layouts and data.)